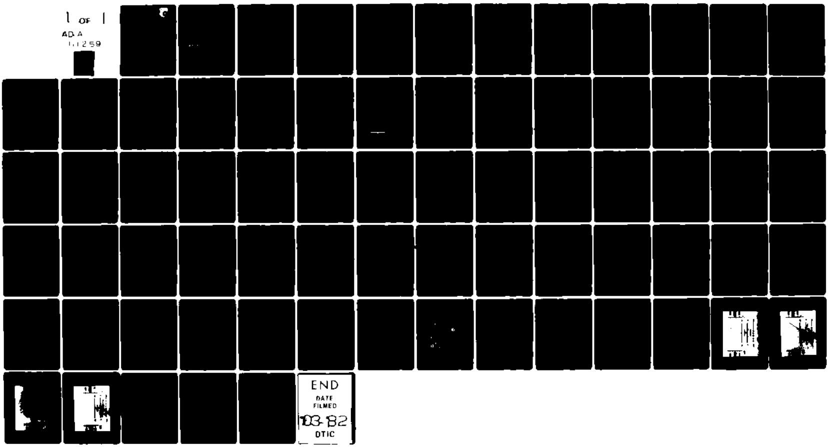
AD-A111 259   BUNKER-RAMO CORP WESTLAKE VILLAGE CA ELECTRONIC SYST--ETC F/G 1/2
SIMULATION REPORT -- ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJEC--ETC(U)
JUN 81 P B LOVERING, D A WARNER, D K PARK   F33615-78-C-3614
UNCLASSIFIED   AFWAL-TR-81-3057   NL



AFWAL-TR-81-3057

SIMULATION REPORT -- ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES

Peter B. Lovering
Debra A. Warner
Deborah K. Park
Matthew Miller

The Bunker Ramo Corporation
Electronics Systems Division
Westlake Village, California

and

Squadron Leader Stuart B. Burdess

Crew Systems Development Branch
Flight Control Division
Flight Dynamics Laboratory

June 1981

Final Report for Period June 1980 to October 1980

Approved for public release; distribution unlimited.

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Stuart B Burdess

STUART B. BURDESS, Sqn Ldr, RAF
Project Engineer
Crew Systems Development Branch
Flight Control Division

Charles R Goss Jr.

CHARLES R. GOSS, Jr., Lt Col, USAF
Chief
Crew Systems Development Branch
Flight Control Division

FOR THE COMMANDER

Robert C. Ettinger

ROBERT C. ETTINGER, Col, USAF
Chief
Flight Control Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIGR, *W-PAFB, OH 45433 to help us maintain a current mailing list".*

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-81-3057	2. GOVT ACCESSION NO. AD-A111 257	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SIMULATION REPORT -- ADVANCED DISPLAY FOR COMPLEX FLIGHT TRAJECTORIES		5. TYPE OF REPORT & PERIOD COVERED Final Report June 1980 - October 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mr. Peter B. Lovering, Ms. Debra A. Warner, Ms. Deborah K. Park, Mr. Matthew Miller, Bunker Ramo Corp.; Sqn Ldr Stuart B. Burdess, Flight Dynamics Laboratory		8. CONTRACT OR GRANT NUMBER(s) F33615-78-C-3614
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bunker Ramo Corporation 4130 Linden Avenue Dayton, Ohio 45432		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project: 240304100
11. CONTROLLING OFFICE NAME AND ADDRESS Flight Dynamics Laboratory (AFWAL/FIGR) Air Force Wright Aeronautical Laboratory (AFSC) Wright-Patterson Air Force Base, OH 45433		12. REPORT DATE June 1981
		13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work was performed by the contractor at the Flight Dynamics Laboratory, Flight Control Division, Crew Systems Development Branch, WPAFB, Ohio

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Attitude Indicator
Attitude Director Indicator
Predictor Display
Aircraft Displays
Display Formats
Electro-optical display formats
Precision approach display

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Several cockpit display problems were revealed during flight tests of complex approach trajectories in support of the Microwave Landing System (MLS) Program. Among these problems were pilot orientation with respect to the approach profile and the runway, verifying proper performance along the prescribed path and cross-checking or monitoring profile computations.

Prior to termination of Air Force participation in the MLS complex trajectory investigations, the Crew Systems Integration Branch, (Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT

Flight Dynamics Laboratory, initiated a graphics display research effort aimed at solving problems identified in earlier testing. A prototype 2-D graphic flight display, originally programmed to be tested in an MLS equipped T-39, was subsequently flown in an in-house simulator experiment.

This document contains a brief background statement regarding the display and describes the simulator experiment, results and recommendations for display improvement. In all, eight rated Air Force Pilots of varying backgrounds flew approximately 264 curved, multi-segmented glideslope approaches in a variety of simulated wind conditions. Data collection included objective performance with respect to the desired flight path and pilot opinion on each of the new display features. Generally, pilots were favorably impressed with the display concept and recommended further development.

FOREWORD

This report documents the results of a 2-D Graphics Display development and flight simulation effort conducted as part of the Advanced Control Display Concepts Program. The results of the flight simulation experiment are reported herein.

The program was conducted in the Flight Dynamics Laboratory (AFWAL/FIGR), Wright-Patterson AFB, Ohio and was partially sponsored by the Federal Aviation Agency. The program was managed by Squadron Leader Stuart B. Burdess, Program Manager, AFWAL/FIGR.

This report was prepared by the Human Factors Group, Electronic ystems, Bunker Ramo Corporation, Westlake Village, California, under USAF Contract No. F33615-78-C-3614, Project No. 24030410D. Mr. Robert A. Bondurant, III, (AFWAL/FIGR) was the contract monito:

The authors wish to acknowledge assistance from Messrs. Steve Ingle and Larry Gearhart, Simutech, Inc. for their efforts and cooperation in the aero/navigation model interfacing task; to Capt Ken Race, AFWAL/FIGD and to Messrs. Ed Collins, AFWAL/FIGX and Al Meyer, Technology, Inc. for providing a well managed and highly reliable simulation facility for the experiment. We sincerely appreciate the advice provided by Mr. John Murray, Systems Consultants, Inc. In addition, special thanks to Ms. Cindy Gier for accurate and untiring administrative support in the preparation of test plans, schedules, and this report.

This research effort was performed between June and October 1980. The authors submitted the report in March 1981.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

1. BACKGROUND

A series of Flight Profile Investigations conducted in the 1971 - 1979 time period revealed a number of problems associated with curved, multi-segmented precision approach paths such as those envisioned in the use of the Microwave Landing System (MLS). Among these were:

a. There was no satisfactory way for the pilot to confirm that all data entry and profile computations were correct during the accomplishment of an approach.

b. It was extremely difficult for the pilot to correlate his position on the approach with that desired. Desired bearing, distance and altitude at checkpoints along the path were indicated on the terminal area charts and three separate instruments were provided in the cockpit for use in the crosscheck; however, the pilot simply did not have the time to make use of them.

c. Frequently, pilots complained of losing orientation in the patterns. Often they lost track of their position with respect to the overall profile and the runway and found it difficult to anticipate turns, changes in vertical path, etc.

Recognizing that these display deficiencies posed potentially serious limitations to full utilization of an emerging terminal area navigation system, personnel in the Crew Systems Development Branch initiated a graphic display development effort aimed at providing some viable solutions to the problem. Participants in the program were Bendix Corporation, Bunker Ramo Corporation, the Air Training Command (Instrument Flight Center) and the Flight Dynamics Laboratory.

Development work started in 1978 as part of the MLS effort using a specially equipped T-39A in which a color CRT had been installed for the test. The aircraft was equipped with Time Referenced Scanning Beam (TRSB) receivers, a digital Automatic Flight Control System and a computer and software required for complex trajectory generation. The Bendix Corporation, under USAF Contract No. F33615-77-C-2053 programmed the display. Air Force participation in inflight MLS research and development and the Bendix contract was terminated on 31 December 1978 before any flight testing could be accomplished.

In late 1979, a decision was made to continue research in this area through an in-house simulation effort. Rationale for this decision was:

a. Replacement of the Instrument Landing System (ILS) with MLS facilities remains an international goal. If the aviation community, including the Air Force, intends to use the system safely and efficiently, several crew/system interface issues must be addressed; displays are one of the most important issues. The Crew Systems Development Branch has more background information and experience with flight crew issues as they pertain to MLS operations than any other Air Force organization.

b. Precision navigation problems associated with existing Air Force missions such as the C-130 All Weather Aerial Delivery (AWADS), Low Altitude Parachute Extraction System (LAPES) and others are not unlike those identified in MLS testing. Increased use of digital navigation computers and graphic displays in the cockpit provide a variety of opportunities to improve the kinds of information provided to the pilot flying these missions, thereby improving precision, flexibility and safety with the added benefits of reduced pilot workload.

c. Other emerging technologies such as unconventional flight and trajectory control being examined in Control Configured Vehicles (CCV), the integration of Fire and Flight Control systems (IFFC) and Integrated Flight Trajectory Control (IFTC) all pose formidable challenges to cockpit display designers. At the same time, systems supporting these

technologies generate the kinds of information required by the pilot for effective monitoring and control. The problem rests with how this information should be integrated and displayed for cockpit use.

Consequently, in January 1980 Simulation Technology, Inc. (SIMUTECH) with Systems Control, Inc. (SCI) was tasked under an existing contract to modify the navigation model in an existing A-7 cockpit simulator in preparation for graphic display testing. The Bunker Ramo Corporation, under an existing contract, was tasked with providing software for the display compatible with the PDP/RAMTEK configuration in the facility and the interface required for the flight simulator experiment. Bunker Ramo was also responsible for designing and conducting the experiment. The experiment was conducted, using eight rated Air Force pilots, in September 1980.

2. OBJECTIVES

The primary objective in this research effort was to examine, in terms of pilot acceptability and performance, the use of integrated attitude, predicted aircraft performance and desired path information for lateral control. In this initial effort an attempt was made to put, with the exception of power, all information required for control along the approach path on a single display surface. The display was intentionally kept as simple as possible so that modifications or additions resulting from this experiment could be based solely on stated needs of pilots participating in the effort.

SECTION II

METHODOLOGY

1. SUBJECTS

A total of eight rated Air Force pilots were selected for participation in this feasibility study. Flying experience ranged from 1200 to 5000 hours. All had completed flight training in T-37/T-38 aircraft. Subsequent experience included tours as instructor pilots in pilot training (2), tanker/transport operations (4), heavy helicopter (1) and fighters (1).

2. INDEPENDENT VARIABLES

The 2-D display was examined under varying levels of four sets of conditions: task, wind velocity, wind direction and whether the pilot was advised of wind conditions prior to the 5 degree descent.

The flight profile was divided into seven parts, each representing a different piloting task. They were as follows:

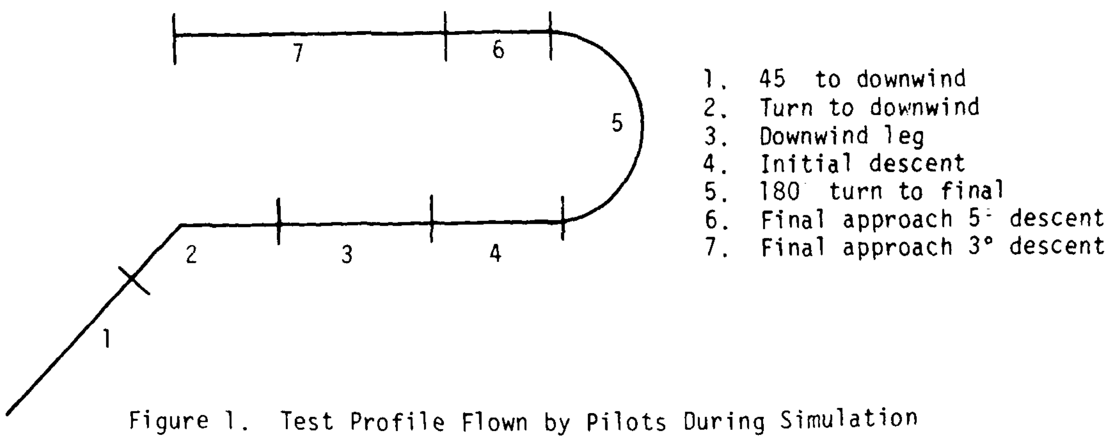


Figure 1. Test Profile Flown by Pilots During Simulation

Wind velocities examined were 10 and 25 knots, with a velocity of zero being flown during the training and baseline runs only.

Eight wind directions were simulated and presented. They included winds from 045 degrees, 090 degrees, 135 degrees, 180 degrees, 225 degrees, 270 degrees, 315 degrees, and 360 degrees.

Finally, pilot knowledge and lack of knowledge of wind conditions prior to the 5 degree descent were examined to detect potential differences in performance.

3. DEPENDENT VARIABLES

Pilot performance was measured for:

a) roll attitude stability,

b) overshoot/undershoot during course interception,

c) frequency of deviations from prescribed course, and

d) magnitude of deviations from prescribed course.

Each measure of performance was recorded at a rate of two times per second, and summarized for each of the seven events or tasks in the flight profile.

Data parameters required for objective performance measurements were:

TABLE 1

DATA PARAMETERS

Parameter	Scaled in:	Range
Heading	Degrees	360°
Actual Ground Track	Degrees	360°
Desired Ground Track	Degrees	360°
*Airspeed	Knots	100-450
*Altitude	Feet	0-20m
*Course Deviation	Feet	0-20m

Parameter	Scaled in:	Range
Distance to Touchdown	N. Miles	0-200
*Vertical Velocity	Ft/Min	± 5000'/min
Bank Angle	Degrees	± 90°
*Flight Path Angle	Degrees	± 30°
*Glideslope Deviation	Feet	± 500m
Pitch Attitude	Degrees	± 90°
*Flight Dir Pitch Command	Full Scale	± 1

Parameters indicated by an asterisk were summarized for each leg of the approach. The summary output provided Average Error (AE), Absolute Average Error (AAE), Root Mean Square (RMS) and Standard Deviation.

4. DESIGN

In addition to flying a baseline run, each subject was required to fly 32 runs of the same approach, once under each of the combinations of wind velocity, wind direction, and advisement of wind conditions (2 X 8 X 2). The design matrix used for the study was constructed by creating a 32 X 32 Latin square and selecting eight of the sequences such that all of the conditions were presented an equal number of times in the pilots' first runs.

Each pilot was briefed (see Appendix A) and permitted an opportunity to ask questions. He then completed three trials under calm wind conditions. The performance data from his third run, also flown under calm winds, was collected as baseline data. In all three cases he was advised that winds were calm. The first 16 runs of the matrix were flown subsequent to the original three. On a separate day the remaining 16 were flown. Following the 32nd run, the subject was required to complete a questionnaire in which he was asked to subjectively assess the display.

TABLE 2

TEST MATRIX

Pilot 1	
1= 1	17=25
2= 2	18=10
3=32	19=24
4= 3	20=11
5=31	21=23
6= 4	22=12
7=30	23=22
8= 5	24=13
9=29	25=21
10= 6	26=14
11=28	27=20
12= 7	28=15
13=27	29=19
14= 8	30=16
15=26	31=18
16= 9	32=17

Pilot 2	
1= 5	17=29
2= 6	18=14
3= 4	19=28
4= 7	20=15
5= 3	21=27
6= 8	22=16
7= 2	23=26
8= 9	24=17
9= 1	25=25
10=10	26=18
11=32	27=24
12=11	28=19
13=31	29=23
14=12	30=20
15=30	31=22
16=13	32=21

Pilot 3	
1=10	17= 2
2=11	18=19
3= 9	19= 1
4=12	20=20
5= 8	21=32
6=13	22=21
7= 7	23=31
8=14	24=22
9= 6	25=30
10=15	26=23
11= 5	27=29
12=16	28=24
13= 4	29=28
14=17	30=25
15= 3	31=27
16=18	32=26

Pilot 4	
1=14	17= 6
2=15	18=23
3=13	19= 5
4=16	20=24
15=12	21= 4
6=17	22=25
7=11	23= 3
8=18	24=26
9=10	25= 2
10=19	26=27
11= 9	27= 1
12=20	28=28
13= 8	29=32
14=21	30=29
15= 7	31=31
16=22	32=30

Pilot 5	
1=20	17=12
2=21	18=29
3=19	19=11
4=22	20=30
5=18	21=10
6=23	22=31
7=17	23= 9
8=24	24=32
9=16	25= 8
10=25	26= 1
11=15	27= 7
12=26	28= 2
13=14	29= 6
14=27	30= 3
15=13	31= 5
16=28	32= 4

Pilot 6	
1=24	17=16
8=25	18= 1
3=23	19=15
4=26	20= 2
5=22	21=14
6=27	22= 3
7=21	23=13
8=28	24= 4
9=20	25=12
10=29	26= 5
11=19	27=11
12=30	28= 6
13=18	29=10
14=31	30= 7
15=17	31= 9
16=32	32= 8

Pilot 7	
1=27	17=19
2=28	18= 4
3=26	19=18
4=29	20= 5
5=25	21=17
6=30	22= 6
7=24	23=16
8=31	24= 7
9=23	25=15
10=32	26= 8
11=22	27=14
12= 1	28= 9
13=21	29=13
14= 2	30=10
15=20	31=12
16= 3	32=11

Pilot 8	
1=31	17=23
2=32	18= 8
3=30	19=22
4= 1	20= 9
5=29	21=21
6= 2	22=10
7=28	23=20
8= 3	24=11
9=27	25=19
10= 4	26=12
11=26	27=18
12= 5	28=13
13=25	29=17
14= 6	30=14
15=24	31=16
16= 7	32=15

TABLE 3

WIND COMBINATIONS

1. Given, 10 knots, 045°
2. Given, 10 knots, 090°
3. Given, 10 knots, 135°
4. Given, 10 knots, 180°
5. Given, 10 knots, 225°
6. Given, 10 knots, 270°
7. Given, 10 knots, 315°
8. Given, 10 knots, 360°
9. Given, 25 knots, 045°
10. Given, 25 knots, 090°
11. Given, 25 knots, 135°
12. Given, 25 knots, 180°
13. Given, 25 knots, 225°
14. Given, 25 knots, 270°
15. Given, 25 knots, 315°
16. Given, 25 knots, 360°
17. Not given, 10 knots, 045°
18. Not given, 10 knots, 090°
19. Not given, 10 knots, 135°
20. Not given, 10 knots, 180°
21. Not given, 10 knots, 225°
22. Not given, 10 knots, 270°
23. Not given, 10 knots, 315°
24. Not given, 10 knots, 360°
25. Not given, 25 knots, 045°
26. Not given, 25 knots, 090°
27. Not given, 25 knots, 135°
28. Not given, 25 knots, 180°
29. Not given, 25 knots, 225°
30. Not given, 25 knots, 270°
31. Not given, 25 knots, 315°
32. Not given, 25 knots, 360°

5. TEST APPARATUS

a. Cockpit

A single-seat A-7 type cockpit was used for the experiment. The instrument panel and side consoles had been extensively modified for other display experiments. Included in the modifications was a center panel, seven-inch diagonal color CRT used in this experiment. The only other instrument used was a tachometer mounted above and to the right of the CRT. Controls used in the test were the throttle and flight control/trim system.

b. Experimenter's Console and Simulation Facilities

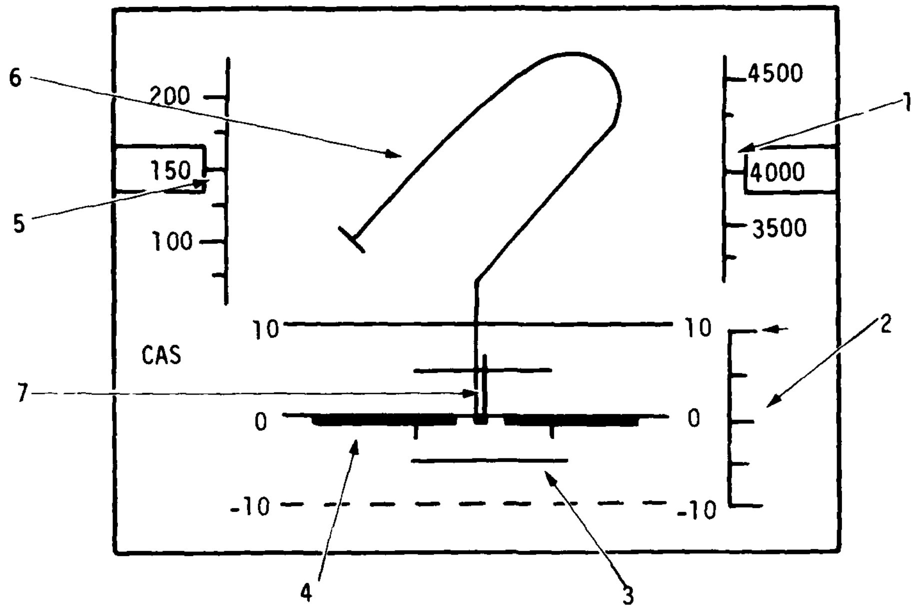
The experimenter's console was equipped with a CRT display duplicating that on the pilots' instrument panel. The experimenter had controls for operating data recording equipment also. A description of the test facility is provided in Appendix C.

6. DISPLAY

The display was designed originally to test new display parameters in the lateral axis only. These parameters were the computer generated approach profile, the predicted flight path symbol and their integration into the overall display.

The profile was a single scale graphic view of the path to be flown. The entire profile rotated with aircraft heading changes so that current heading was always at the top of the display. In this way, drift was always shown the same as it would be seen in a real world, i.e., head up manner. The approach profile moved toward the bottom of the display surface to the center of the aircraft symbol when on course, at a rate scaled to groundspeed. Software was written so that no part of the path appeared below the aircraft symbol at any time.

The path predictor line was originally intended to show predicted aircraft position from the present (at the aircraft symbol) to 15 seconds

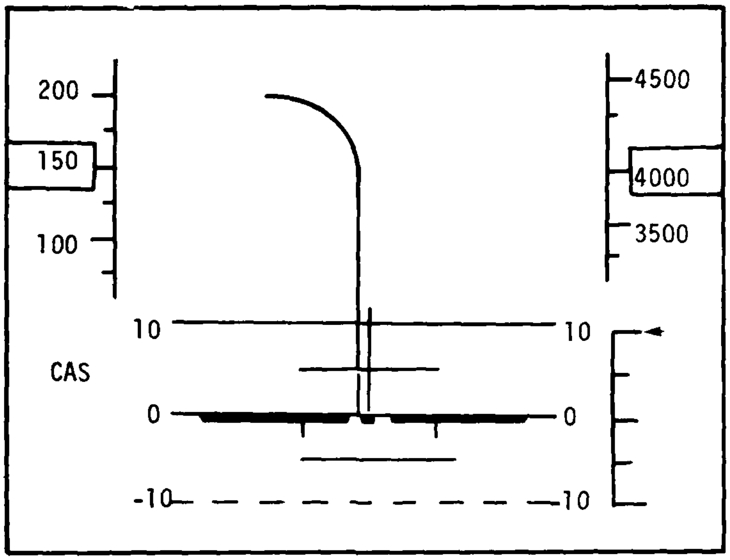


1. Altitude scale
2. Glideslope scale
3. Pitch attitude scale
4. Aircraft symbol
5. Airspeed scale
6. Approach profile
7. Path predictor

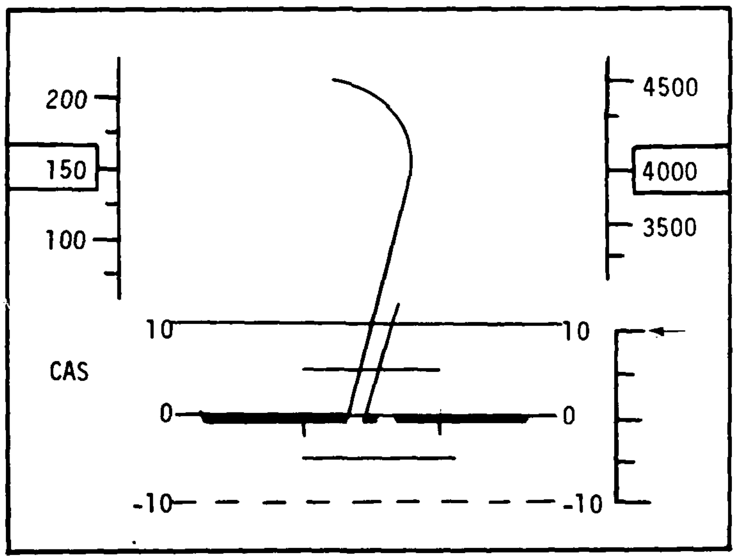
Figure 2. Features of the Experimental Display Format

ahead based on groundspeed, turn rate and drift. During the experiment it was found that a last minute software revision in another display area just prior to simulation evaluation, caused an inadvertent increase in path length to approximately 26 seconds. The pilots were not told and did not notice this discrepancy during the experiment.

The path predictor was designed to show drift in the same way as the approach profile. For example, with a 10 degree right drift angle, both the approach profile and the predictor would be deflected 10 degrees right of vertical when the aircraft was on or parallel to course in straight flight (as shown in Figure 3).



Straight Flight



Left Crosswind/Right Drift

[redacted]

Figure 3. Display Showing Wind Effects

The remaining unconventional display feature was the outside-in-configuration of the aircraft symbol. Due to the inherent dynamics of the path predictor and the overall configuration of the integration effort it was felt that this might be the more compatible way to go and, in fact, might be better than the current convention for precision final approach work.

Remaining display elements were essentially standard. Airspeed and altitude displays were the same as those previously used in Digital Avionics Information System (DAIS) studies, as was the pitch attitude scale. The glideslope deviation scale was essentially standard in appearance except that it was linear as opposed to conventional, angular deviation displays. The scale displayed $\pm$ 40 feet of deviation from glideslope center throughout the approach. The pitch steering command, located at each wingtip of the aircraft symtol, rotated with the aircraft in roll and provided commands to intercept and maintain the glideslope.

It should be noted that the overall configuration of the display was intentionally kept as simple as possible since this was only the first of several developmental steps planned to optimize the lateral axis and to examine other potential areas of improvement such as vertical path displays and range and range rate depiction. For details on display changes expected to result from this experiment and those recommended by pilots participating in the experiment, refer to Section V, Recommendations.

7. FLIGHT PROFILE

The flight profile is shown in Figure 4. This particular design was selected for its similarity to those flown in the MLS profile tests and the fact that it was one of tte most challenging in terms of the pilot's flight control and monitoring tasks.

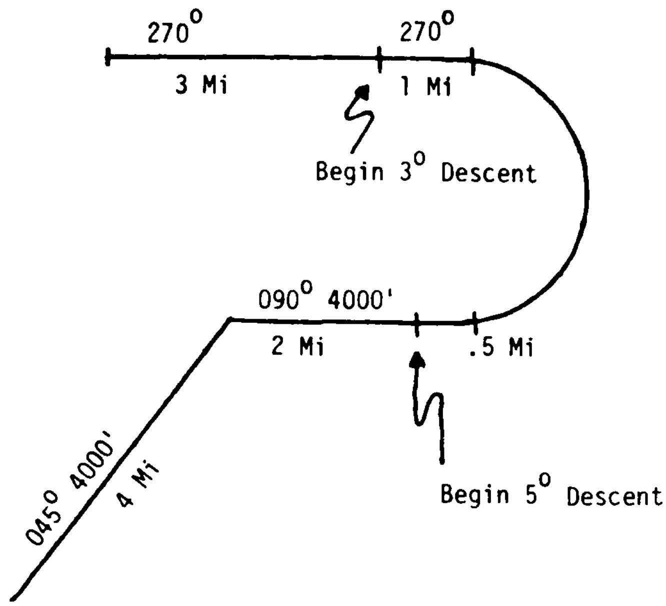


Figure 4. Approach Profile

Flight started from an initial conditions position on a heading of 045 degrees at 4000 feet and 150 knots indicated airspeed (KIAS). The aircraft model was trimmed and in stable flight conditions at the start of each run and positioned at the start of the approach path approximately four miles from the downwind leg. The profile was approximately 14.5 miles in length. Turns in the early MLS tests were computed on a one-mile radius. A one and one-half mile radius was used in this simulation to make the pattern more compatible with aircraft approaching at higher speeds and to keep bank angles at an acceptable level when tailwinds were encountered during the turn. Prior to starting each approach, display scaling was set so that the pilot could see the entire approach profile. Once the run was started, scaling doubled to increase sensitivity and precision, displaying only the upcoming portion of the flight profile.

The approach path was flown at 4000 feet to glideslope interception at a point one-half mile prior to beginning the 180 degree turn to final. A five-degree descent was flown throughout the turn and to a point three

nautical miles on final where the approach angle shallowed to three degrees. The glideslope indicator measured $\pm$ 40 feet of displacement from center through the entire descent. Approaches terminated at 50 feet above ground level at what would be the approach end of the runway.

8. PROCEDURES

All runs were started from the same position on the profile. The aero model and cab initially went through a computerized trim sequence; the final trim steps were accomplished via aircraft controls by the subject pilot. When this procedure was complete and he was ready to start the run, the subject stated "Ready" and the simulator was set into operation. Subjects were required to make two transmissions during each run -- one on the initial approach leg and one at three miles on final when the glideslope transitioned from five to three degrees. At the initial call, the experimenter gave approach clearance and, when appropriate (in accordance with the experimental conditions), the winds. At the three-mile call, the experimenter gave landing clearance and winds. The approach was programmed to end automatically at what would be the threshold of the landing runway, and the setup procedure was initiated by the experimenter for the next run.

SECTION III

RESULTS

The results of the statistical analyses conducted on the objective performance measures, and the subjective questionnaire data are presented below.

An analysis of performance data - maximum and minimum vertical velocities, and RMS measures of crosstrack, vertical steering, glideslope and airspeed errors - showed that performance varied significantly using the display, as a result of task, wind velocity, and wind direction. At 10 and 25 knots of wind significant effects were found for (1) task, $F\ (24,7140) = 151.85$, $p < .00001$, (2) wind velocity, $F\ (4,1773) = 3.84$, $p < .00423$, and (3) wind direction, $F\ (28,7104) = 2.04$, $p < .00118$. A detailed explanation of the statistical procedures used in data analyses is given in Appendix F.

Significant interaction effects included those for task and wind direction, $F\ (168,\ 6944) = 1.92$, $p < .00001$, and wind velocity and knowledge of wind conditions prior to the five-degree descent, $F\ (4,\ 1785) = 2.49$, $p < .04160$.

An examination of the questionnaire responses showed that the participants felt, had the approaches been real, the path predictor would have helped their ability to make the approach accurately and safely, $D = .541$, $p < .05$. They rated the path predictor's ability to aid them in judging future aircraft position with respect to the path good to excellent, $D = .600$, $p < .01$. When asked to state a preference between making an approach using a course deviation indicator versus a graphically displayed lateral track, the respondents preferred the latter, $D = .600$, $p < .01$.

Since the display's symbols and scales were presented in color, the pilots were asked to assess the appropriateness of the colors assigned to each. The colors of the flight path, pitch cues, aircraft symbol, path predictor, background, airspeed scale, altitude scale, glideslope scale and all associated readout windows were deemed satisfactory,

$p < .008$, using a binomial test. The color of the pitch ladder was considered satisfactory, $p < .07$, with one of the eight respondents expressing a preference for red rather than white.

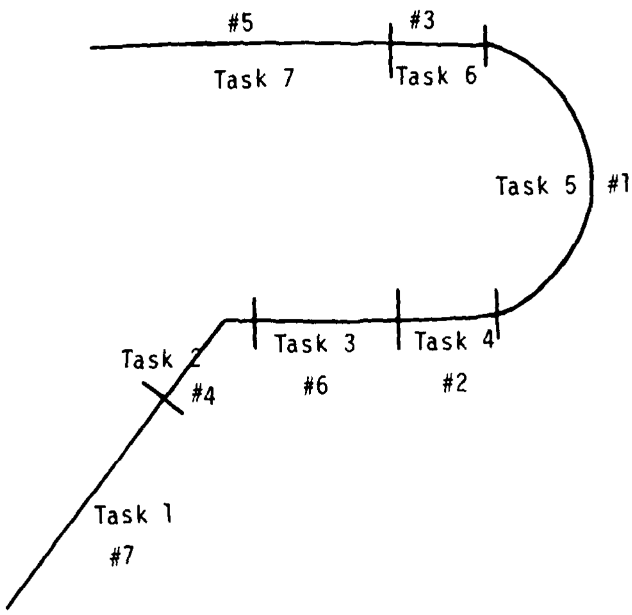


Figure 5. Task Difficulty Ratings

Pilots were asked to rate the difficulty of each of the seven tasks of the flight profile. Their responses were averaged accordingly, where #1 indicated "most difficult" and #7, "least difficult".

Objective analyses showed, for an average across crosstrack error, vertical steering error, glideslope error, and airspeed error, the tasks to rate in performance as follows, with #1 indicating the most error, #7 indicating the least.

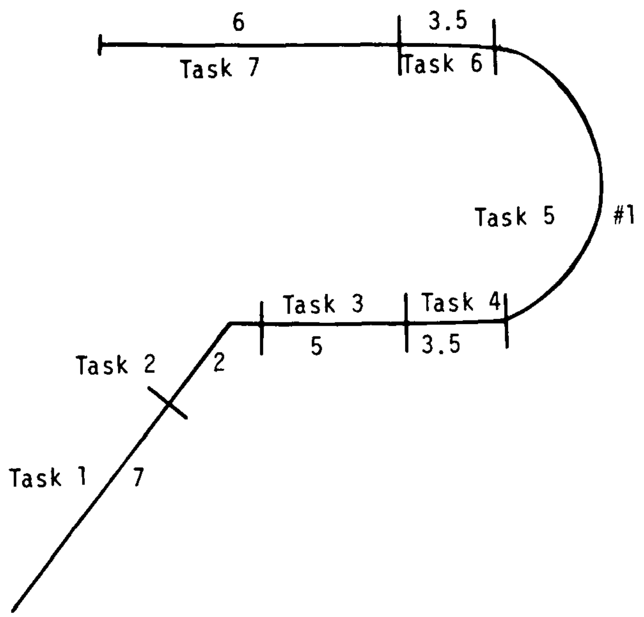


Figure 6. Crosstrack Error Results

Since Task 5 was rated most difficult by the pilots and rated first in terms of total error, a brief assessment of quantitative error data was made. Average cross track error $\pm$ 3 standard deviations for all approaches flown revealed that the largest average error on any approach was 2291 feet and that maximum error indicated at 3 standard deviations was 4200 feet. Fairly large errors were expected during the test since pilots were experimenting during early runs and classical demonstration/performance training was not provided. If the nature of the experiment had been different and a thorough training program preceeded data collection, it is reasonably safe to expect lateral error would have been on the order of $\pm$ 2000-2500 feet with scale factors used during the test.

Table 4 gives a tabular listing of objective and subjective results by task. As can be seen, pilots rated tasks 1, 3, and 7 as being the three easiest legs. This was supported by the statistical data which showed least performance errors for these tasks.

TABLE 4

COMBINED OBJECTIVE AND SUBJECTIVE DIFFICULTY RESULTS

TASK	DIFFICULTY	
	SUB	OBJ
1	7	7
2	4	2
3	6	5
4	2	3.5
5	1	1
6	3	3.5
7	5	6

SECTION IV

DISCUSSION

Three major observations were made by the experimenters concerning the ability of the participants to fly the approach using the two-dimensional display. The first observation involves training. With only a minimal explanation of how the integrated display worked, pilots very quickly established their own techniques for using the display. Secondly, there were no obvious control reversals (pitch or roll in the wrong direction) during the experiment nor were any reported by the subjects. Finally, and perhaps most important, when large deviations from course occurred, there was never any real concern expressed over pilot orientation with respect to the intended path or how he would correct the situation. By visual assessment, the pilot had only to pick the way he wanted to return to course. These three aspects alone indicate that the display concept constitutes, at least partially, a solution to some of the display problems encountered during the MLS tests.

Overall, pilots felt that their flight performance would have been better using a flight director than it was with the test display. Ironically, however, they rated their ability to use the approach profile, the path predictor, and with one exception the outside-in aircraft symbol equal to or higher than other, more conventional display features. Several factors could have contributed to this inconsistency, among these being familiarity (as reported by one pilot) and over-all display quality. Another pilot, after indicating that he thought performance would be better with a flight director, remarked that "there is no question that the test display is superior to the flight director." This would lead one to conclude that the pilots, at times, were reporting their feelings about the display concept while others were commenting on the quality of the prototype display.

Unanimous preference for the graphically displayed approach profile over a conventional course deviation indicator was significant and due probably to the fact that pilots could look ahead and anticipate lateral

control requirements. Positive response to the path predictor--the information it provided and the way in which it operated--was significant also and points again to the premise that present and future situation and performance information can be used effectively to control an aircraft.

Subsequent to simulation, several pilots stated that they could have flown more accurately during the early stages of the approach but they knew, like ILS, the requirement for precision increases to a maximum on the final segment. Experimenter observations and accuracy data support this in that accuracy on the last segment was second only to the first leg where the simulator was started in a trimmed, on course configuration. It was apparent to the observer that, from about the midpoint of the 180 degree turn, pilots were concentrating on a smooth interception of the final approach leg in a manner very similar to the way they would on a visual approach.

The summation of error data for each segment revealed that the turn to downwind was second to the 180 degree turn to final in maximum error. This can be misleading in that, by design, crosstrack error was large throughout the turn. Unlike the 180-degree turn, there was no radius computed or displayed for the tracking task. The pilot had to judge when to start the turn in order to make a smooth transition to downwind. All pilots did this by starting the turn 15-20 seconds prior to reaching the waypoint, returning to course on downwind 15-20 seconds after the waypoint. Effectively, they "cut the corner." Crosstrack error was being summed throughout the maneuver, making it look like a tracking error.

Aside from the performance and pilot acceptance issues addressed during the experiment, there remains the data entry and profile computation problem encountered during MLS testing. The fact that the pilot can see results of the computation process and compare the graphic depiction with the approach plate should eliminate gross errors that could occur during data entry. Similarly, if a computation failure occurs during an approach, pattern distortion should cue the pilot immediately.

Taken one step further, careful integration of the right information into the graphic display could be used effectively to reduce or, in time, eliminate the requirement for frequent and time consuming reference to approach plates during an approach. Historically, approach plates have been a source of consternation to pilots. Problems include lighting, finding a suitable place to mount or rest the publications, and currency.

Overall, results of the experiment were very encouraging in terms of pilot acceptance, performance and the fact that all control, except power, could be maintained by reference to a single display. Obviously, additional backup information such as heading, vertical velocity or flight path angle would be desirable for actual flight. The dependence upon these displays, however, and the requirement to mentally integrate the data from them will be greatly reduced.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

a. Pilots were favorably impressed with the new display features.

b. Pilot performance with the display indicated that with further refinement, precision control to ILS or even better standards may be achieved.

c. Training requirements are minimal since lateral control and situation displays are relatively straight forward.

d. The graphic display eliminates the kind of position orientation problem encountered using the Flight Director in complex trajectory operations.

e. A display of this type can be used effectively to increase pilot confidence in profile construction and computation and aid in monitoring system operation.

f. The display provided the kind of information a pilot needs to judge present and future situation and performance in terms directly related to his flight control tracking task.

2. RECOMMENDATIONS

Results of the experiment indicated that refinements to the display could improve pilot performance. It is therefore recommended that further research work be carried out to incorporate the following suggested changes.

a. Approach Profile

1. As expected, symbols showing the different segments of the approach (specifically, lateral and vertical path changes) need to be added. Recommend that the symbols shown at Figure 7 be added to the display.

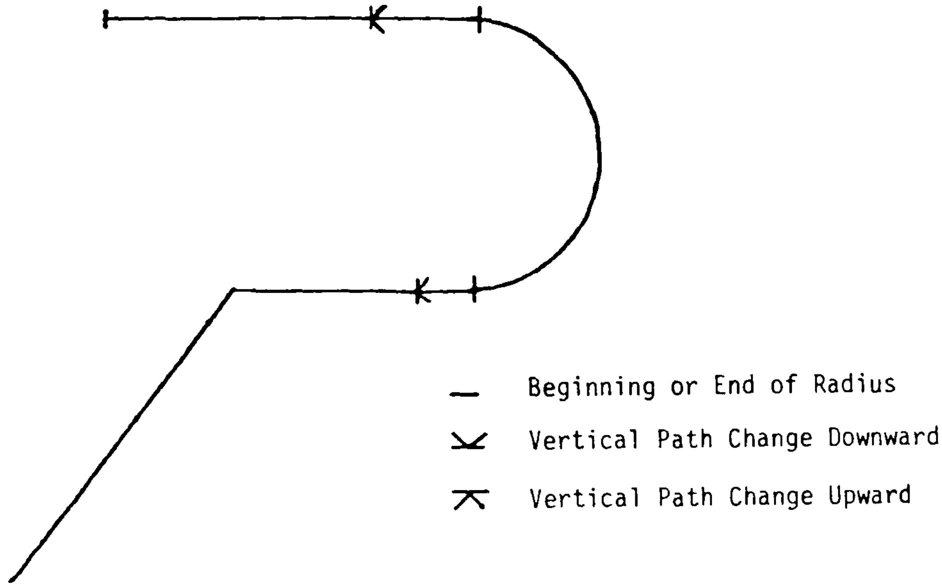


Figure 7. Recommended Along Path Symbology

2. Glideslope indicator and pitch steering command operation were distracting at the start of the approach. Glideslope deviation computations were not started until the point along the approach path where the descent was started. This caused the glideslope deviation indicator to "pop" into view and the pitch steering command became erratic during the transition from level flight. It is recommended that glideslope computations be extended outward on the profile to the waypoint preceeding that at which the descent is started.

3. Scaling used in this experiment was not designed for nor did it achieve the degree of accuracy expected of a precision approach aid in terms of vertical and lateral performance. It is recommended that part task studies of other scale factors be conducted to determine their effects on accuracy, flyability and pilot acceptance.

b. Pitch Commands

Glideslope performance may have been affected by the type (display) and quality (computation) of the pitch commands used in simulation. It is recommended that (1) algorithms used for the pitch command computations be checked for accuracy and state-of-the-art performance and (2) the pitch command display be modified as shown in Figure 8 to make steering errors more noticeable in maneuvering flight and take the first steps toward the development of a display that shows vertical path guidance in proper perspective.

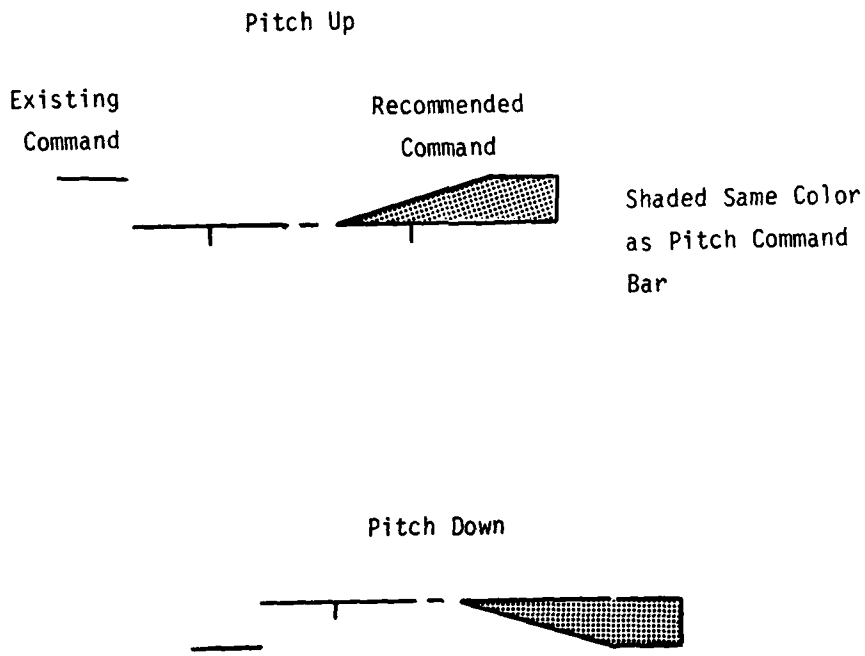


Figure 8. Recommended Pitch Command Modification

APPENDIX A

PILOT INSTRUCTIONS

PILOT INSTRUCTIONS

Purpose - The overall purpose of this experiment is to evaluate the use of predicted path information for lateral control. The path to be flown is shown on the display also and is used with the path predictor display.

Configuration - Roll attitude is displayed outside-in. A standard display shows bank angle with a moving horizon line and bank pointer. In this display the horizon line remains stationary and the aircraft symbol banks.

The path predictor line, extending forward from the center of the aircraft symbol shows future aircraft position under existing flight conditions. For purposes of this test the line is 15 seconds "long". Used in conjunction with desired flight path symbology, the predictor shows the angular relationship to course as well as lateral deviation. With the path predictor superimposed over the desired path, the aircraft will intercept or remain on the desired course.

The desired approach path is a scaled, computer generated depiction of the path to be flown. In this simulation the display is configured in a heading up arrangement so that performance (path predictor) and the desired f ight path will show drift in the same manner as the pilot sees it looking at the real world. The lateral control task is one of flying the aircraft so as to keep the path predictor superimposed over the approach path or in a relationship to the path that will result in a smooth intercept. Notice that the display allows a pilot to establish course intercepts at a variety of angles as necessary to intercept the desired course at a point of his selection. Remaining display features, airspeed, altitude, pitch command and glideslope deviation indicator operate in a standard manner.

The pilot's task in this experiment is to "fly" the simulator along the displayed approach profile from the initial conditions position to the end of the approach. The approach consists of a 45 degree approach to the downwind leg, a short downwind, a 180 degree turn to final on a

5 degree glidepath followed by a 4 mile straight in final approach. The 5 degree descent starts just prior to the 180 degree turn. At three miles from touchdown the glideslope angle changes from 5 degrees to 3 degrees for the remainder of the task.

Initial conditions for initiating the approach are:

a. A/S - 150 KIAS

b. Alt. - 4000'

c. Hdg. - 045°

d. Power - approximately 91% RPM

When the simulator is established at the IC position and trimmed, the pilot and experimenter will coordinate starting the run. When the run is started and the pilot has the simulator trimmed, he will advise the experimenter as if he were calling tower or approach control and advise "starting approach." At that point, the experimenter will clear him for the approach and on half of the approaches (randomly), provide test wind conditions. When the approach proceeds to three miles on final and the 5 degree - 3 degree glideslope transition occurs, the pilot will call again for landing clearance. The experimenter will clear him for landing and, on all approaches, provide the winds. The pilot will continue to the point of touchdown where the return to IC will be made.

The subject pilot's primary task is to fly the aircraft as accurately as possible, along the published approach path while maintaining 4000 feet, the 5 degree approach path or 3 degree final segment. Airspeed throughout the approach to touchdown will be maintained at 150 KIAS. Approximate power settings for the test will be 91 percent while maintaining 4000 feet, 85 percent on the 5 degree approach segment and 89% on final. These will vary as a function of wind direction and velocity.

Two types of data will be collected during the experiment; objective performance data on flight profile accuracy and subjective pilot opinions on the display.

Each pilot will fly 32 runs of approximately 5 minutes duration each. They will be flown in two groups of 16 runs each with a break of 5 minutes between each run. The pilot will complete a questionnaire at the end of the second day.

APPENDIX B

PILOT QUESTIONNAIRE

Immediately after completion of the final run, each pilot was given a 26 question questionnaire on which to record his comments on the experiment. The questionnaire addressed the overall simulation, display and each feature making up the display. Pilots were also asked to compare the display with current flight directors, to comment on color coding of the various elements, and to make any suggestions they felt might improve the display. Following is a consolidation of ratings and comments.

1. The inputs you made using the stick and throttle changed attitude and performance indications on the graphic display. Judging from the correlations between the amount of each input and the resultant changes on the graphic display, rate the realism/accuracy of the simulator's controls.

   A. I perceived that the simulator's bank/pitch control inputs (stick) created realistic and comparable changes in attitude and performance on the graphic display

(Check one)	Pilots:
☐ under all conditions.	2 - 5
☐ under most conditions.	3 - 4 - 6 - 7
☐ about half the time.	
☐ under a few conditions only.	1 - 8
☐ under no conditions.	

Comments:

1. The simulator felt very heavy & sluggish. Sometimes it seemed to react more to where the stick was positioned rather than the amount of stick pressure being used.

3. Bank initially did not seem to correlate to stick inputs.

5. Very realistic, this allowed for smooth instrument flying (i.e. compensate altitude for airspeed).

6. Display lag was very apparent. It took several approaches before I trained myself to integrate the jerkiness of the display.

7. Airspeed to was not effected fast enough in relation to stick movement.

8. Response to pitch inputs seemed more accurate than bank inputs. Several times I thought I'd rolled out level only to find I was still in a bank.

   B. I perceived that the simulator's power control inputs (throttle) created realistic and comparable changes in speed indications on the graphic display

(Check one)	Pilots:
☐ under all conditions.	
☐ under most conditions.	1 - 2 - 4 - 5 - 6 - 8
☐ about half the time.	
☐ under a few conditions only.	3
☐ under no conditions.	7

Comments:

3. Power response and associated airspeed change seemed slow for fighter type A/C.

4. For the initial portion of the descent, I felt I had to "push over" to get to the command bars and then since I was not on the command bars immediately I felt there was an oscillatory command that took quite a while to damp out.

5. When the speed was excessive, a large reduction in power was necessary. At times idle power (at detent) was unable to reduce the airspeed realistically. This comment applies to excessive speeds which should not be approached while flying instruments ($\simeq$ 170 knots).

6. RPM gauge hard to include in inst. cross check.

7. Speed readout also did not seem fast or slow enough in relation to throttle movement.

2. Compare the performance of this fixed-base simulator with the performance of other fixed-base simulators you have flown.

   This simulator's accuracy/realism/flyability was

(Check one)	Pilots:
☐ superior to other fixed-base simulators.	
☐ somewhat better than other fixed-base simulators.	3* - 4
☐ about the same as other fixed-base simulators.	1 - 2 - 5 - 8
☐ not as good as other fixed-base simulators.	7
☐ much worse than other fixed-base simulators.	6

Comments:

2. Difficult to compare directly since my response to the new displays affects my perception of what the simulator should have done. Also, I had to physically move my hea l to check RPM. Thus most of the time the RPM guage was not in my crosscheck.

3. 1) better than AF sims I have flown
   2) about the same as the civilian 727 & Sabreliner sims I have flown

4. Superior to most but on par with some that I've flown.

5. The A/C represented had a very stable roll rate which is unusually nice! The small discontinuities in the display (i.e. a lower & thus misleading pitch down command bar as the lit down was initiated & the ground track flash - momentary off -) should be corrected.

6. Slow response time from input to display makes smooth control almost impossible. All pitch changes resulted in pilot induced osc.

7. Needs the sounds of the engine(s).

8. All fixed-base sims have drawbacks. I'm most familiar with the F-4 sim, which never seemed to have good/accurate force feel in the stick. This one seemed better in that respect but not so good as noted in 1A.

* 2 answers given; this reflected AF simulators

3. In general, did the symbols and scales on the display move together to portray a realistic picture of flight?

(Check one)	Pilots:
☐ Yes, all of the scales and symbols interacted realistically.	2 - 3 - 5 6 - 8
☐ No, there were some discrepancies which created a less-than-realistic picture of flight.	1 - 4 - 7

If you checked "☐No", describe these discrepancies.

1. The CRT didn't give a smooth flow of change. It jumped a few degrees at a time. Mainly in pitch indications.

4. I felt that the airspeed loss/altitude gain and airspeed gain/altitude loss was a bit excessive. For a trimmed condition w/constant power, a 1 or 2 knot gain for 12 feet of altitude is a little unrealistic. Typically I expect to see 2 to 3 knots for 100 feet.

6. Some sort of pitch axis model glitch exists about 10 sec after glide path inteception. If I knew the "glitch" was there from the beginning I would not have tried to chase it and vertical path following would have been better.

7. Jerky, broken lines could draw your attention away from other cross-check areas.

4. Rate your ability to use each of the following symbols and scales that appear on the display (i.e., is its function clear, and does its movement make sense?).

	Highly Useful	Somewhat Useful	Neither Useful nor Confusing	Somewhat Confusing	Highly Confusing
approach profile	(2 4 5 6 7 8)	(1 3)			
aircraft symbol	(1 2 3 4 5 6 8)				(7)
path predictor	(1 3 4 5 6 8)	(2 7)			
pitch bars	(2 3 4 5 6)	(1)	(8)	(7)	
pitch ladder	(4 6 8)	(1 2 5)		(3 7)	
airspeed scale	(1 2 3 4 5 7 8)	(6)			
altitude scale	(1 3 4 7)	(5 6 8)	(2)		
glideslope scale	(1 4 7 8)	(3 5 6)	(2)		

Comments:

1. Some of the symbols are obviously useful - pitch ladder & a/c symbol. Without them it would be impossible to fly - Their presentation was, however, very effective. The A/C symbol movements were at first confusing due to the years of use of an attitude/horizon indicator. Once accustomed to it, however, it was as good or better than the horizon indicator - for this use (simulator).

2. Path predictor was useful, but somewhat confusing in turns. Pitch ladder was a secondary scale to the pitch bars. Sometimes the pitch ladder was in the way (extra clutter). Never really used the altitude scale. Relied on the pitch bars. Same for glideslope scale. These two scales are needed, but not necessarily on the display.

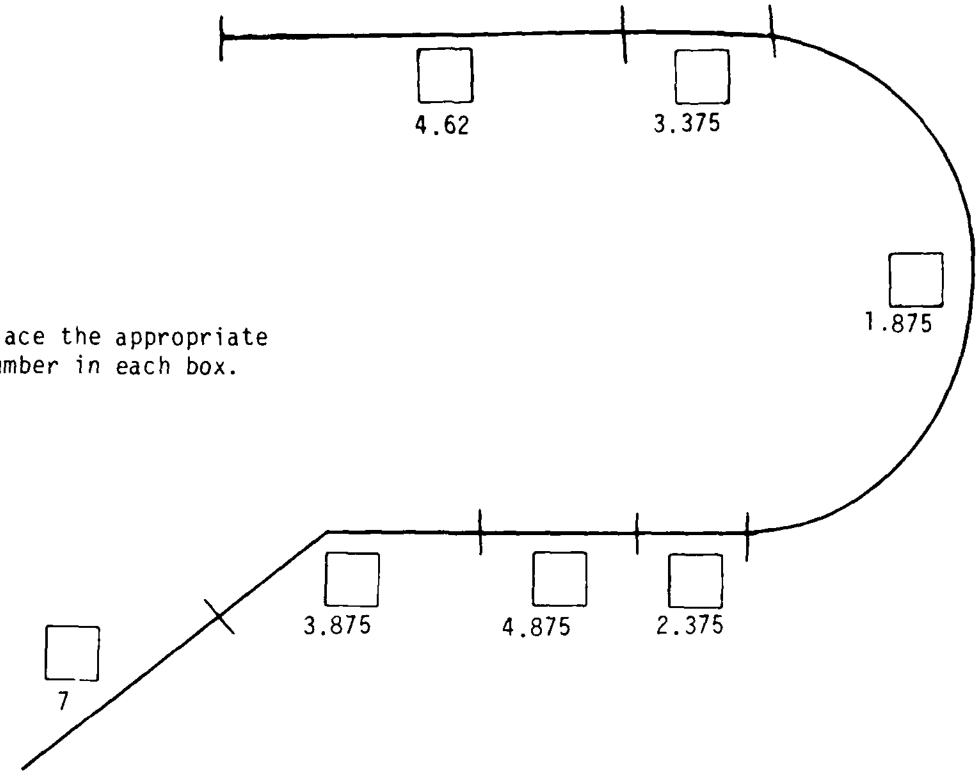
3. (1) unneccessary if system is 100% reliable however without pitch scales the system could fail and any pitch resulting in an attitude unsafe for flt.
   (2) move down in display to be in line with a/c symbol so that scan could be all in one line.

5. The attitude control was difficult. It was very easy to develop a PIO. The pitch bars were useful when this PIO situation developed. The pitch ladder, however, was necessary in the crosscheck as a control instrument to anticipate small corrections and power settings. The altitude scale again was used to anticipate small corrections & power settings. The glidepath scale was very useful during final phase of final approach (1.5 miles on final) to fine tune and predict small corrections.

6. These grades would be lower for black & white display. The alt & a/s readouts do not move vertically along the scale. I found that I had to mentally compute speed and descent rates. No vertical velocity info avail directly.

8. Altitude scale would have been more helpful if there was a better rate input vice trend. What I really mean is I'd like a VVI device to X-check against.

5. Rate the difficulty of each of the legs of the approach by placing a $\boxed{1}$ next to the leg you thought was the most difficult to fly, $\boxed{2}$ next to the leg that was the next most difficult to fly, etc., and $\boxed{7}$ next to the leg that was the least difficult to fly.



Place the appropriate number in each box.

Comments:

1. Rolling out on extended final presented the most difficulty due to sluggish and sometimes unpredictable simulator reactions.

3. (1) need a symbol to inform pilot when he will be starting down glideslope and entering turn. Likewise when slope goes from 5° to 3°.
(2) Suggest that ground track be shown as though aircraft was flown in a standard rate turn thus the depiction would look like a smooth curve rather than a sharp turn.

5. Blocks number 3 & 4 were approx. the same difficulty. As my precision increased I found that block #3 could be accomplished much easier. Block #2 was difficult to recover as a large deviation developed. Block #1 was difficult for the following reason: The roll out was often an overshoot, the predictor would require a turn back to cross the final approach path, which required more judgment resulting in less precision.

6. (1) No warning that G/S is approaching.
   (2) Simulator not smoothly coupled to display.
   (4) Again no warning that G/S angle is changing.

8. I always seemed to be playing catchup during the base turn. I think my problems mostly began with poor altitude control going into the turn. I found on the final approaches where I had my act together soon after base turn roll out, things were easy to keep track of. Makes sense!!

6. Wind velocity and direction were provided at the beginning of each 3° descent ( ). They were, however, provided only on half of the flights prior to the beginning of each 5° descent ( ). Were you able to sense the wind conditions before you were finally told the conditions (i.e., if asked, could you have accurately stated the wind velocity and its direction)?

	Wind Velocity (Check one:)	Pilots:	Wind Direction (Check one:)	Pilots:
A. Yes, always	☐		☐	1 - 4 - 6
B. Yes, usually	☐	1 -4 -6 - 8	☐	5 - 7 - 8
C. Yes, about half the time	☐	2 - 5	☐	2
D. Yes, but not very often	☐	7	☐	
E. No, never	☐	3	☐	3

Comments:

1. Again, once I grew more familiar with the symbology it was easy to judge winds in general.

2. Within maybe 10 knots and 25 degrees. Sometimes didn't bother to deduce wind. Just reacted to display. Wind knowledge helped plan turns through.

3. Never bothered to determine it. My task I felt was simple to fly the symbols and the symbols would correct for the wind so therefore the wind vel. and dir. did not matter to me.

5. The shift of the approach profile would allow the pilot to determine wind direction & velocity. This was most obvious during the dog leg to downwind and the final approach. The exact direction & wind velocity would be difficult to determine precisely but what was available would be very useful to the pilot.

6. For the lighter winds velocity was a guess (headwind or tailwind).

7. If you checked A-D above, what cues enabled you to presume

A. Wind velocity?

Comments

1. Amount of displacement & rate of displacement of flt path predictor.

4. The relative crab angle of the flight path.

5. Angle of approach profile, length of time in turn to final. Time on final.

6. Apparent acft motion along track and around the curves.

7. The length of the time of the turns, i.e., turn to downwind.

8. Amount of over/under shoot on downwind turn & rate of downwind leg.

B. Wind direction?

Comments:

1. Same as above.

2. Angle between top of display and straight line segments of approach path. Also drift in turns & relative speed on straight line segments. Combination of velocity & angle.

4. The path predictor.

5. Angle of approach profile.

6. Drift required to track course.

7. The angle during the 45° to downwind leg.

8. Bank required to establish initial course track.

8. Were you able to adequately assess, using the available symbols and scales on the 2-D display, the appropriate range and range rate required for executing the turn to downwind?

(Check one)	Pilots:
☐ Yes, the symbols and scales provided adequate information.	1 - 2 - 3 - 4 - 5 6 - 7 - 8
☐ No, the symbols and scales did not provide adequate information.	

If you checked "☐ No", what were the difficulties you encountered?

Comments:

2. Only after about 8 runs. Still had problems with latter part of turn after all runs. Not rolling out on course. This is more precise info than what is usually available though.

3. The manner in which I expected the turn did not require me to know range or range rate because as soon as the top of blue lateral index touch the point of turn I rolled into a smooth turn to keep the top of index line on the approach profile line.

9. Were you able to adequately assess, using the available symbols and scales on the 2-D display, the appropriate range and range rate required for executing the 180° turn?

(Check one)	Pilots:
☐ Yes, the symbols and scales provided adequate information.	2 - 4 - 5 - 6 - 7 - 8
☐ No, the symbols and scales did not provide adequate information.	1 - 3

If you checked "☐ No", what were the difficulties you encountered?

Comments:

1. I had difficulty in judging the effects of wind throughout the middle ( ) portion of the turn. I consistently undershot even though I attempted to keep the flight path predictor on the ground track.

3. That was a difficult turn to accomplish because the workload was maximum due to requirement to continually monitor bank, pitch, and power.

8. This didn't bother me too much after I began to get used to the display. I think the times I didn't get it around accurately were due to poor x-check.

10. Was the change in vertical path to a 5° descent indicated adequately using the 2-D display?

(Check one) Pilots:

☐ Yes, the symbols and scales provided adequate "notice" of the vertical path change. 1 - 4 - 5 6 - 8

☐ No, the symbols and scales did not provide adequate "notice" of the vertical path change. 2 - 3 - 7

If you checked "☐ No", what additional information would you have liked to see?

Comments:

2. No warning and scale would move down very rapidly.

3. Need some symbol to alert pilot when 5° change is needed.

6. Some form of warning is necessary to prevent having to catch up with the desired track. A small line across the display or a flashing G/P caret or anything that reminds you the glide path interception is near.

7. A more slower approach to the glid pe.

11. Was the change in vertical path to a 3° descent indicated adequately using the 2-D display?

(Check one) Pilots:

☐ Yes, the symbols and scales provided adequate "notice" of the vertical path change. 1 - 4 - 5

☐ No, the symbols and scales did not provide adequate "notice" of the vertical path change. 2 - 3 - 6 7 - 8

If you checked "☐ No", what additional information would you have liked to see?

Comments:

2. Final approach point marked on display.

3. Same as above.

5. The initial runs were flown with less precision and the 3° descent was often inadequate to call my pitch change. The later runs were flown with better control and the 5° → 3° change was noticed on the pitch bars!

6. The only way I could tell I was on the 3° was if I had the 5° "wired". I could see the pitch command change. I only saw this a few times. My "3 mile final calls" were usually estimate

7. Same as above.

8. I think you need to have something more pronounced for the change to 3° GS. Maybe blank the < for 3-5 seconds at a rapid rate.

12. Rate your overall performance for <u>each</u> of the seven measures listed below

	Excellent	Good	Average	Below Average	Poor
Track intercept/following:	☐	☐ (1 2 3 4 5 8)	☐ (6)	☐ (7)	☐
Bank attitude control:	☐ (1)	☐ (6 2 5)	☐ (4 8)	☐ (3 7)	☐
Pitch attitude control:	☐	☐ (2 3 5)	☐ (1 4)	☐ (6 7 8)	☐
Airspeed control:	☐	☐ (4)	☐ (1 2 5 8)	☐ (3 7)	☐ (6)
Altitude control:	☐	☐ (1 2 3 4 6)	☐ (5)	☐ (7 8)	☐
Glideslope intercept, 5° descent:	☐	☐ (1 3 4)	☐ (5 8)	☐ (2 6 7)	☐
Glideslope intercept, 3° descent:	☐	☐ (1 3 4 5)	☐ (2 6 8)	☐ (7)	☐

Comments:

1. I think I would have done better if I were use to flying. I haven't flown since April 1978.

3. (1) A bank scale would help so that when a certain bank is required the bank can be determined (ie standard rate turn mark if all turns were shown at standard rate.
(2) An autopilot would be excellent (no deviations).

6. My ego would like to blame the display lag problem for the overall poor performance.

7. The responses were not fast enough in relation to stick and throttle movement. The jerky screen indications were very distracting.

8. I must admit to being a bit lazy up to the point of the final approach phase. I think I had the attitude that I could accept something less than full attention to the TASK & then salvage the approach in the final portion. Probably caused myself lots of extra work that way.

13. Had you been able to fly the same approach using a flight director rather than the 2-D CRT display, rate how you think you might have performed these same tasks.

Using the flight director, my performance for each of the following seven measures would probably have been.

Much Better	Somewhat Better	About the Same	Somewhat Worse	Much Worse	
☐ (7)	☐ (2)	☐ (3 4 8)	☐ (1 5 6)	☐	for track intercept/ following
☐ (3 4 7)	☐ (6 8)	☐ (1 2)	☐ (5)	☐	for bank attitude control
☐ (1 4 7)	☐ (5 8)	☐ (3 6)	☐ (2)	☐	for pitch attitude control
☐	☐ (1 4)	☐ (2 3 5 6 8)	☐ (7)	☐	for airspeed control
☐	☐ (4 8)	☐ (1 2 3 5 6)	☐ (7)	☐	for altitude control
☐ (6 7)	☐ (2 4 5 8)	☐ (1 3)	☐	☐	for glideslope intercept, 5° descent
☐ (6 7)	☐ (2 8)	☐ (1 3 4 5)	☐ 41	☐	for glideslope intercept, 3° descent

Comments:

4. Of course I think I could do better overall in an airplane I am familiar with; with a system I have used for 1800 hrs.

5. The 2-D CRT display was very useful for heading tracking interception, etc. I am unsure of the increase in performance I would obtain from a conventional pitch indicator.

6. Subjective answers. Can't fly a predicted curved path with flight director. My answers assume the two presentation are in acft. There is no question that the test display is superior to flight director.

7. The digital readout, I think, is a much better indicator than dials or tape!

14. Had these approaches been real, do you think the path predictor would have helped or hindered your ability to make the approach accurately and safely?

(Check one)	Pilots:
☐ The path predictor would have helped a great deal.	5 - 6 - 7
☐ The path predictor would have helped somewhat	1 - 2 - 3 - 8
☐ The path predictor would have neither helped nor hindered.	4
☐ The path predictor would have hindered somewhat.	
☐ The path predictor would have hindered a great deal.	

Explain

1. It gave me a better indication of when to begin my turns & also of what effect my particular bank angle was going to have on the flight path. I rarely over-shot my track on all except the mid 180° turn point. I never under-shot any other than 180°.

2. Would like to know more about bank angles demanded by the display. Will it let me get into steep banks to place the predictor?

3. The only way it would help is by knowing were you will be in 15° secs however a flight director corrected for winds you can trust that if you follow the pitch and bank steering bars you will be lined up.

4. Knowing a final approach course, I think many pilots would like to see a heading readout for making an initial drift correction and as a crosscheck on the path predictor.

5. It provides an accurate bank feedback to the pilot allowing for precise bank input & quicker crosscheck capabilities.

6. It eliminates my need to mentally compute drift angles.

15. Given a choice, would you prefer the flight director or the 2-D display for making approaches in your current (or most recent) aircraft?

(Check one)	Pilots:
☐ I would much prefer the flight director.	7
☐ I would somewhat prefer the flight director.	2
☐ No preference, both are equally adequate.	3 - 4 - 8
☐ No preference, both are equally inadequate.	
☐ I would somewhat prefer the 2-D display.	1 - 5
☐ I would much prefer the 2-D display.	6

Explain

1. I think it gave me a much better indication of my relative position & freed my mental attention to other things.

2. More faith. Haven't seen the 2-D display in bright sun or under vibration.

4. Currently I am used to and very knowledgeable in the use of flight director systems, but I feel that with the same amount of time using the 2-D display, I would feel as confident in that system.

5. The requirement to handle all the approaches & lack of familiarity raises a question in my mind on which system is best. I believe that a more precise approach can be flown with the 2-D display.

7. Smooth indications!

8. I'd like to see the 2-D display in actual flight conditions because there will always be some cues you get from the aircraft that can't be duplicated in the sim.

16. Given a choice, and assuming "real flight", would you prefer a course deviation indicator (CDI) or a graphically displayed lateral track for making approaches in your current (most recent) aircraft?

(Check one)	Pilots:
☐ Much prefer a CDI	
☐ Somewhat prefer a CDI	
☐ No preference, both are adequate	
☐ No preference, both are inadequate	
☐ Somewhat prefer a graphically displayed lateral track	2 - 5
☐ Much prefer a graphically displayed lateral track	1 - 3 - 4 - 6 - 7 - 8

Comments:

1. The graphically displayed track leaves little or no room for misinterpretation of CDI displacement.

2. Would tell you position along track.

3. Assume CDI not corrected for winds and no flt. director.

4. If the graphic display were to give me an idea of range, I feel it would be far better than a CDI/DME for making correction to a course.

5. Both would be nice to have. The graphical display lateral track did not give me the deviation in feet that I would like to know. From familiarity with CDI, a pilot knows that a degree of error at a distance can be converted to a distance, at what error or lateral deviation am I unsafe with the graphical display?

6. Much clearer presentation of the "real world situation".

8. Gives me a chance to establish rate & trend.

17. The display was presented in color. Rate the appropriateness of the colors assigned to the symbols and scales. (Check either the Satisfactory or Not Satisfactory column for each symbol/scale listed.)

Symbol/Scale	Assigned Color	Satisfactory	Not Satisfactory: State Preferred Color
Flight path (track)	red/orange	☐ 1 2 3 4 5 6 7 8	☐ ________

Symbol/Scale	Assigned Color	Satisfactory	Not Satisfactory: State Preferred Color
Pitch cues	red/orange	☐ 1 2 3 4 5 6 7 8 ☐	
a/c symbol	green	☐ 1 2 3 4 5 6 7 8 ☐	
Path predictor	blue	☐ 1 2 3 4 5 6 7 8 ☐	
Pitch ladder	white	☐ 1 2 3 4 5 6 8 ☐	7 Red
Background	black	☐ 1 2 3 4 5 6 7 8 ☐	
Airspeed scale	white (-on-black)	☐ 1 2 3 4 5 6 7 8 ☐	
> Readout window	black-on-white	☐ 1 2 3 4 5 6 7 8 ☐	
Altitude scale	white (-on-black)	☐ 1 2 3 4 5 6 7 8 ☐	
> Readout window	black-on-white	☐ 1 2 3 4 5 6 7 8 ☐	
Glideslope scale	red/orange	☐ 1 2 3 4 5 6 7 8 ☐	
> Indicator arrow	white	☐ 1 2 3 4 5 6 7 8 ☐	

Comments:

1. I think a white aircraft symbol is preferrable but would be confusing with white pitch lines. Blue pitch would be more appropriate but up on skyward and bright red for down on earthward. This would be more easily related to.

3. Unless there is a way of changing color of a/s, alt, and pitch ladder when they go out of limits capable of being set by pilot.

6. The use of color was very helpful. More confusion would result with an all black & white display. The wingtip pitch command bars would be hard to sort out if they didn't contrast.

8. I was happy with the colors.

18. Was there ever a time when symbols and/or scales overlapped and you became confused by them?

(Check one)	Pilots:
☐ No, I was never confused by the symbols and/or scales overlapping.	1 - 4 - 5 6 - 8
☐ Yes, I was confused by the symbols and/or scales overlapping.	2 - 3 - 7

If you answered "☐Yes", state which symbol(s) and/or scale(s) overlapped and caused the confusion.

2. A/C symbol and pitch ladder and pitch cues would overlap and hinder fine adjustment.

3. The pitch ladder occasionally confused me.

7. Level flight 0———0 should be the broken line instead of the -10 lines.

19. The a/c symbol is an "outside-in" configuration. Rate this symbol's ability to provide a clear, understandable picture of aircraft roll attitude.

(Check one)	Pilots:
☐ excellent	2 - 6 - 8
☐ good	1
☐ average	3 - 4
☐ below average	5 - 7
☐ poor	

Explain:

1. It took some getting use to but once I did I felt extremely comfortable with it.

3. Would like to try identical tasks with inside-out configuration.

4. It is good for small angles of bank, but higher bank angles coupled with the oscillations I had previously mentioned made it difficult to determine a bank angle.

5. Most pilots with experience are familiar with the "inside-out" configuration. I believe that it is easy to learn this system if only instrument flying is accomplished, however, as a pilot I would like the horizon on the situation indicator agree with my visual observations!

6. That's what I'm used to seeing on other attitude indicators.

7. There is a need for a bank angle indicator.

8. I never was confused about the information displayed by the A/C symbol.

20. The path predictor was added to the a/c symbol to further aid the pilot in judging future aircraft position with respect to the path. Rate the predictor's ability to provide you with this information.

(Check one)	Pilots:
☐ excellent	1 - 5 - 6 - 7 - 8
☐ good	2 - 3 - 4
☐ average	
☐ below average	
☐ poor	

Explain:

2. Good because it considers wind. Otherwise you still have to consider cu-rent a/c position, predictor position and rate of intercept. May increase workload, especially in turns.

6. On the turns I know if the predicted path was outside the curve - my turn would be wide. I only had to increase bank until the predictor crossed the desired track. I could even decide if correction was going to be fast or slow.

8. Path predictor was useful.

21. The path predictor is configured to show what the aircraft's lateral position would be with respect to the track 15 seconds from the present time if current flight conditions (attitude, power) were maintained. Rate its sensitivity.

Fifteen (15) seconds are: (check one)	Pilots:
☐ too long	2 - 4
☐ about right	1 - 3 - 5 - 7 - 8
☐ too short	5

Comments:

2. Very seldom followed up on a 15 sec lag. Generally want finer control, especially in turns.

6. I would prefer 30 seconds. 15 seconds is workable but I think I could fly a smoother approach with 30 sec.

22. In this simulation, was the amount of deflection (movement to right or left) in the predictor comparable to the bank input made?

(Check one)	Pilots:
☐ No, there was too much deflection per input.	7
☐ No, there was too little deflection per input.	4
☐ Yes, deflection and input seemed comparable.	1 - 3 - 5 - 6 - 8
	2 - no answer

Comments:

1. But, there seemed to be a lag in deflection when back-stick pressure was used while banked. This resulted in adding more back pressure and getting a very large deflection.

2. Doesn't this depend on the wind?

8. I could have paid better attention to that but I think it's OK.

23. What information was desired by you that did not appear on the display?

Comments:

1. Ground speed - it makes a difference when on final with repeat to pitch angle. Possibly - power setting - it would help maintain better airspeed control.

2. Final approach fix.

3. Bank indication.

4. Heading and VVI.

5. The only additional information to help "me" control the airspeed better would be the RPM "TACK", this is not necessary but desirable.

6. Heading. Easy to live without heading for this test but impossible in real world. Your winds were all 45° apart so easy to compute. Real winds aren't that nice. (See 4, 5, 10.)

7. Degrees, of bank.

8. Climb & descent rate.

24. What information was provided on the display that you did not need or use?

Comments:

1. Nothing - I used it all.

2. Everything was used, but altitude and glideslope scales were secondary checks.

3. Pitch ladder, however actually need for safety purposes. I really feel bank indicator is needed for safety purposes also.

4. None.

5. All information was used.

6. I used everything.

7. Pitch bars.

8. None. Display was clear & generally all information was useful.

25. What information would you have preferred to see elsewhere in the cockpit rather than on the display?

Comments:

2. Altitude.

3. None.

4. None.

5. Nothing.

6. None.

7. Nothing.

8. VVI for x-check.

26. Make additional comments below concerning the feasibility of the 2-D graphics display. Feel free to make criticisms of its current configuration, and suggestions for improvement.

Comments:

1. I think it is a very good idea. In time of stress a crosscheck tends to break down and having all the information on one display would help prevent that.

2. Should be set up so lines don't break up with movement. When path projector & track are overlapped, small movements result in all kinds of small segments switching on & off, resulting in a loss of resolution & fine control for the pilot.

3. Have already made recommendations above.

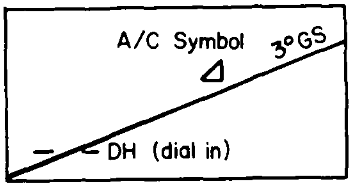
4. I feel the 2-D graphics display is a good concept for aircraft operations. I found it relatively easy to use and it had most of the information in front of me which I would like to have when flying an approach. Overall I think its a good system.

5. It was very easy to fly and very little preparation would be necessary to accomplish the approach in a very precise manner. I would like to see an "inside-out" version to compare with this 2-D display.

6. Keep up the development. It has the potential to greatly improve navigation display information. The less mental gymnastics a pilot has to do in the terminal approach phase of flying the better off he is.

7. None.

8. Would it be feasible to show a side on view of the glide path with a bug showing deviation from GS? I'm thinking of something like the GCA controller sees on his scope during a PAR.



APPENDIX C

SIMULATOR FACILITIES

SIMULATOR FACILITIES

The simulator consisted of interconnected facilities as shown in Figure 1. A functional description of each system element is provided below.

a. PDP 11/50

Configuration Control - used to set up the cockpit controls and display configuration prior to each run.

Display Assembly - generated image listings to be further processed by the Ramtek raster symbol generator. Data from the simulation models was used for the graphic display format.

Flight Control Sampling and Scaling - buffered and scaled flight control data to be used by simulation model.

Simulation Model - provided all necessary aircraft parameters to be used in display processing.

Data Recording - recorded performance data on magnetic tape.

Data Reduction - an off-line program reduced the raw real-time recorded data into meaningful data that could be analyzed.

b. Ramtek

Display Generation - processed image lists to display on 525 line raster monitors. Color display generators were used.

c. Cockpit

Flight Control - digitized analog stick, rudder, and thrust control inputs and buffered the resultant data for transmission to the 11/50.

d. Support Equipment

Console Terminal - system operators input/output device to the 11/50.

Printer and Card Reader - hard copy input/output to the 11/50.

Disk Drive - mass storage device for the operating system.

Magnetic Tape Drive - mass storage device for data collection.

Discrete and Analog Input/Output - input/output port from the 11/50 to all cockpit and experimenter consoles' subsystems.

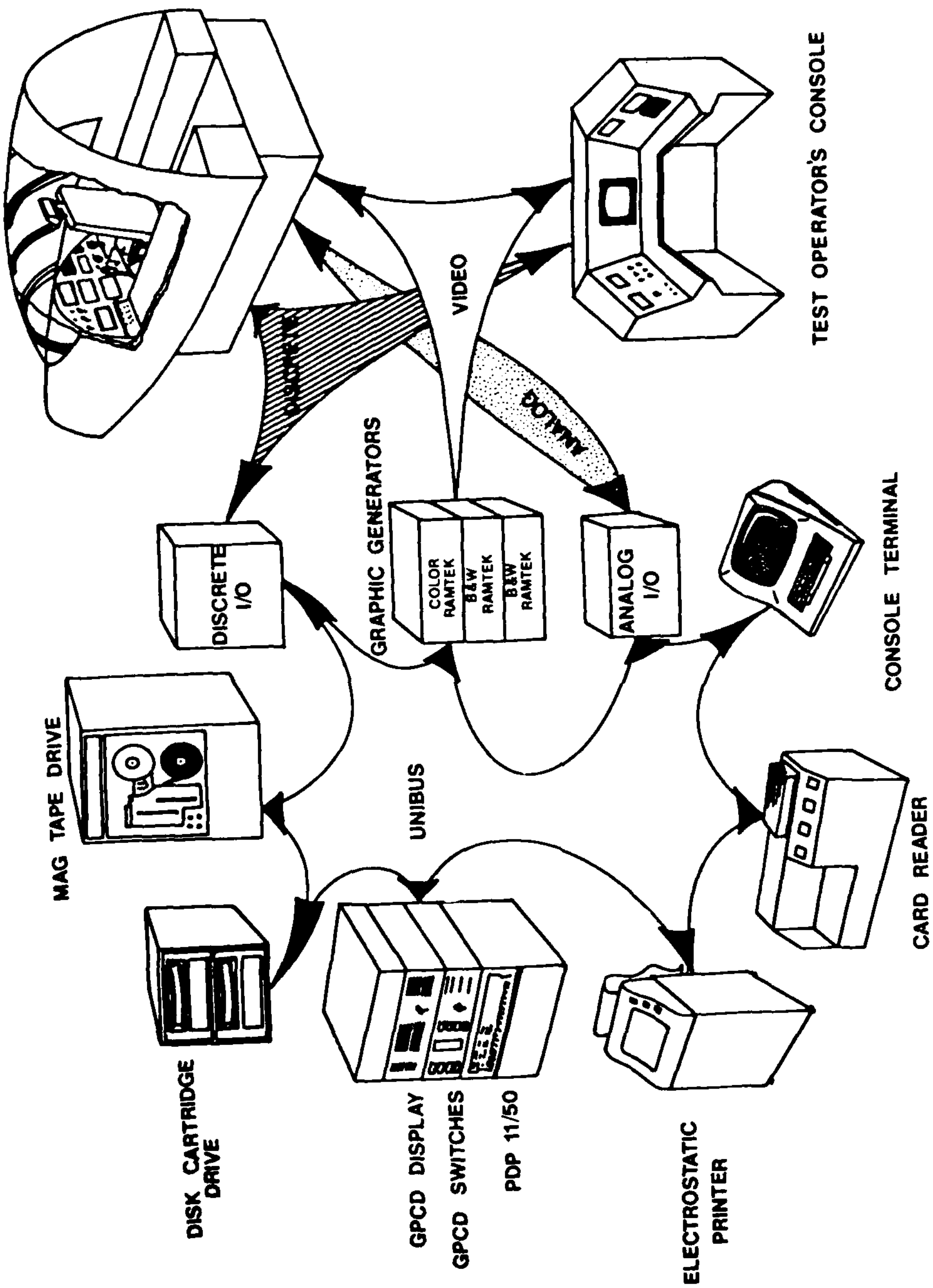


Figure C-1. Simulator Facility Configuration

APPENDIX D

CONTINUED DATA ANALYSIS

APPENDIX D

CONTINUED DATA ANALYSIS

The following printouts reflect the results of finite intersection tests performed on the data collected in the 2-D CRT Display Feasibility Study. The job name on the banner page, i.e., the first three alphanumerics, correspond to these contrasts within each significant effect tested:

<u>Effect</u>

	Dependent Variables	Independent Variables	Job Name(s)
1.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK	T35, T36, T37
2.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	WIND DIRECTION	F28, F29, F30, F31
3.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 1 X WIND DIRECTION	F24, F25, F26, F27
4.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 2 X WIND DIRECTION	F20, F21, F22, F23
5.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 3 X WIND DIRECTION	F16, F17, F18, F19
6.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 4 X WIND DIRECTION	F12, F13, F14, F15
7.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 5 X WIND DIRECTION	FT1, FT2, FT3, F11
8.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 6 X WIND DIRECTION	FT5, FT8, FT9, FTB
9.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	TASK 7 X WIND DIRECTION	FT6, FTC, FTD, FTZ
10.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	WIND VELOCITY	FT4
11.	XTRKRMS,GSERMS, VSERMS,ASERRMS*	WIND VELOCITY X INFO	FT7
12.	MAXHDOT,MINHDOT,* GSERMS,ASERRMS	TASK	F32, F33, F34

* XTRKRMS indicates RMS of crosstrack error; GSERMS, RMS of glideslope error; VSERMS, RMS of vertical steering error; ASERRMS, RMS of airspeed error; MAXHDOT, maximum vertical velocity; and MINHDOT, minimum vertical velocity.

CAUTION: A discrepancy exists in the naming of the four dependent variables appearing on each FIT. They are to be renamed accordingly:

F32	Variable 1 = MAXHDOT
F33	Variable 2 = MINHDOT
F34	Variable 3 = ASER
	Variable 4 = GSE
All others	Variable 1 = ASER
	Variable 2 = VSE
	Variable 3 = XTRK
	Variable 4 = GSE,

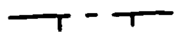
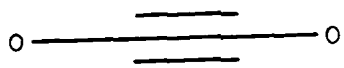
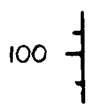
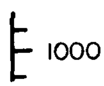
where MAXHDOT indicates maximum vertical velocity; MINHDOT, minimum vertical velocity; ASER, airspeed error; GSE, glideslope error; VSE, vertical steering error; and XTRK, crosstrack error.

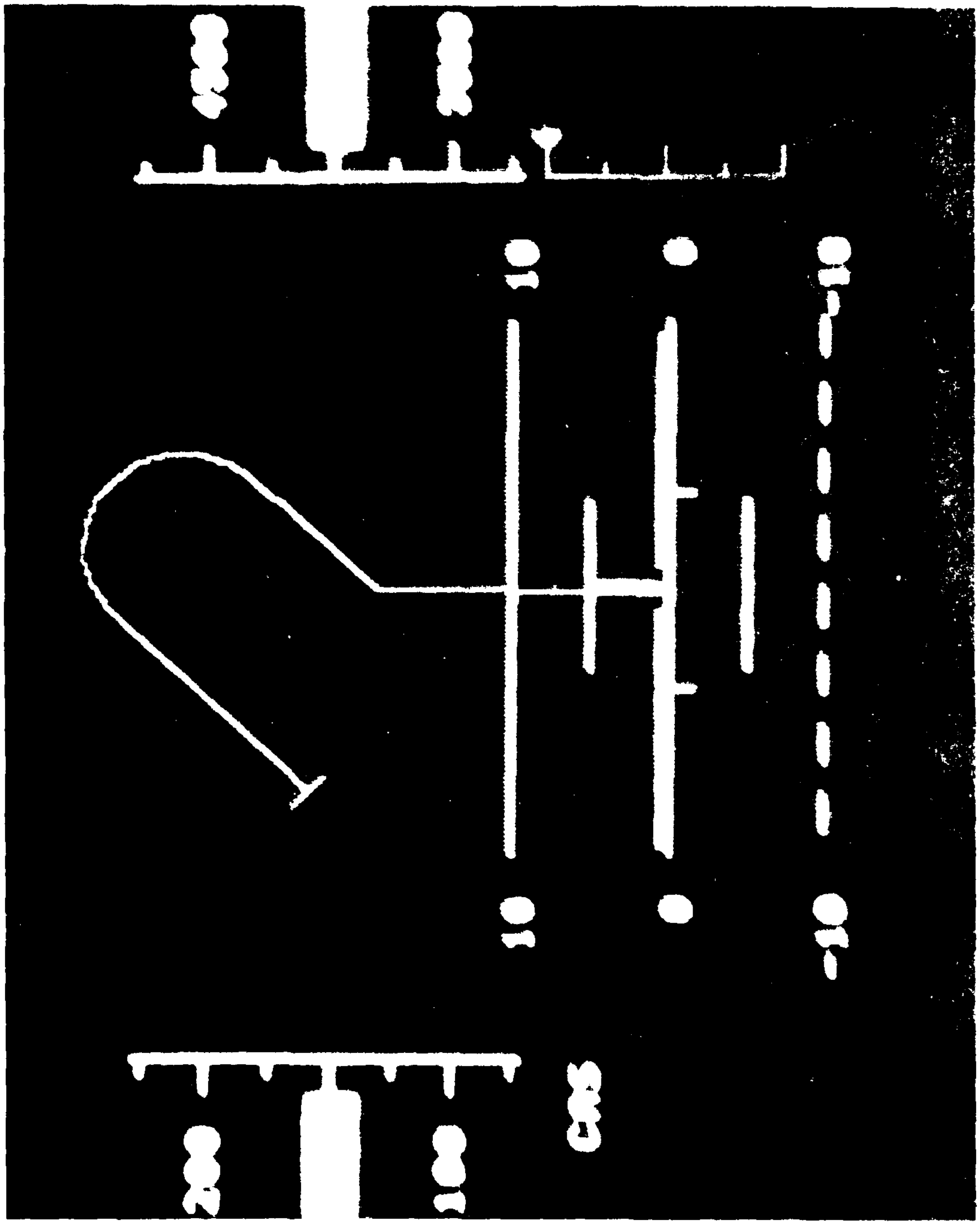
FIT jobs are arranged in the following order:

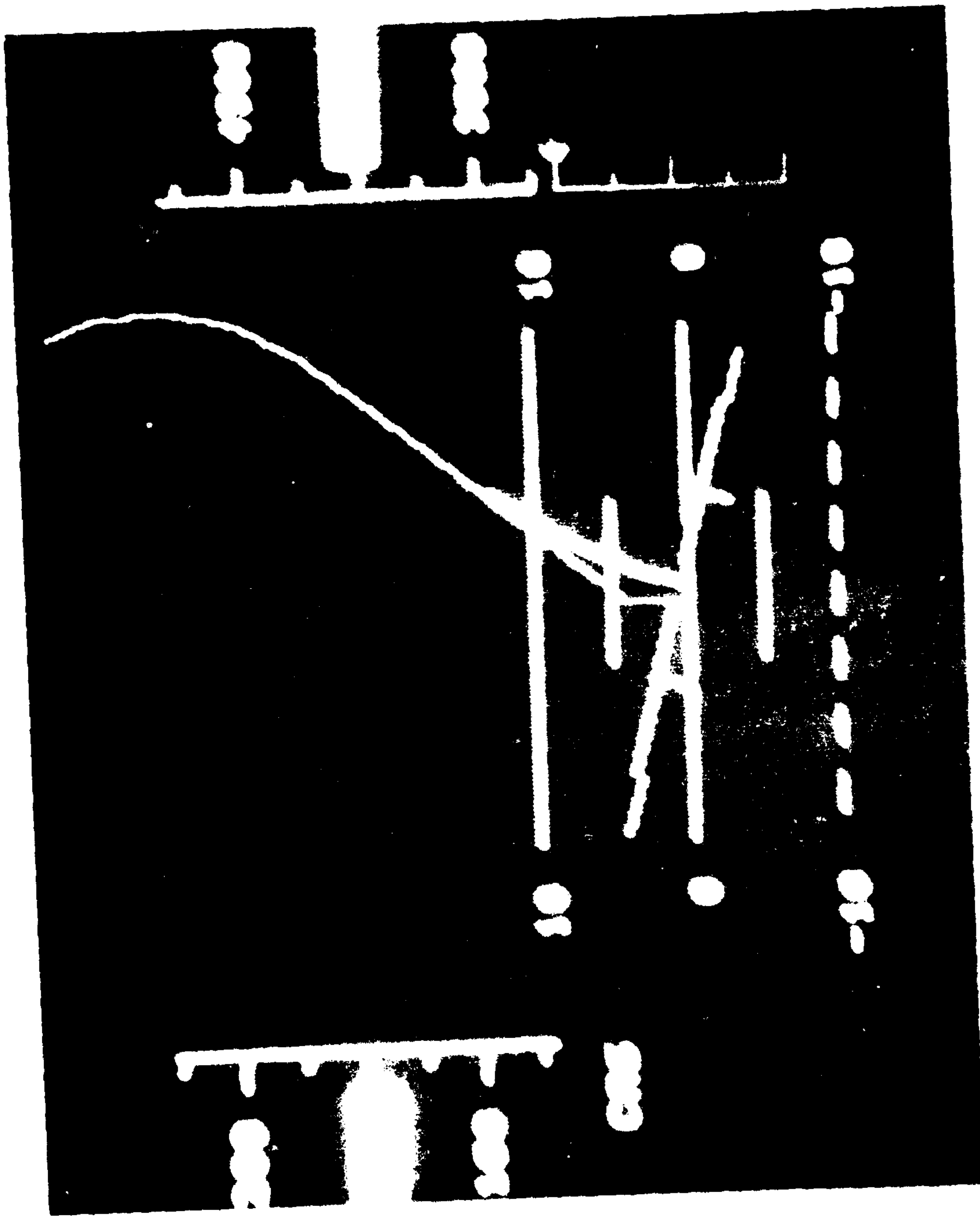
F11	F20	F30	FT2	FTC
F12	F21	F31	FT3	FTD
F13	F22	F32	FT4	FTZ
F14	F23	F33	FT5	
F15	F24	F34	FT6	
F16	F25	F35	FT7	
F17	F26	F36	FT8	
F18	F28	F37	FT9	
F19	F29	FT1	FTB	

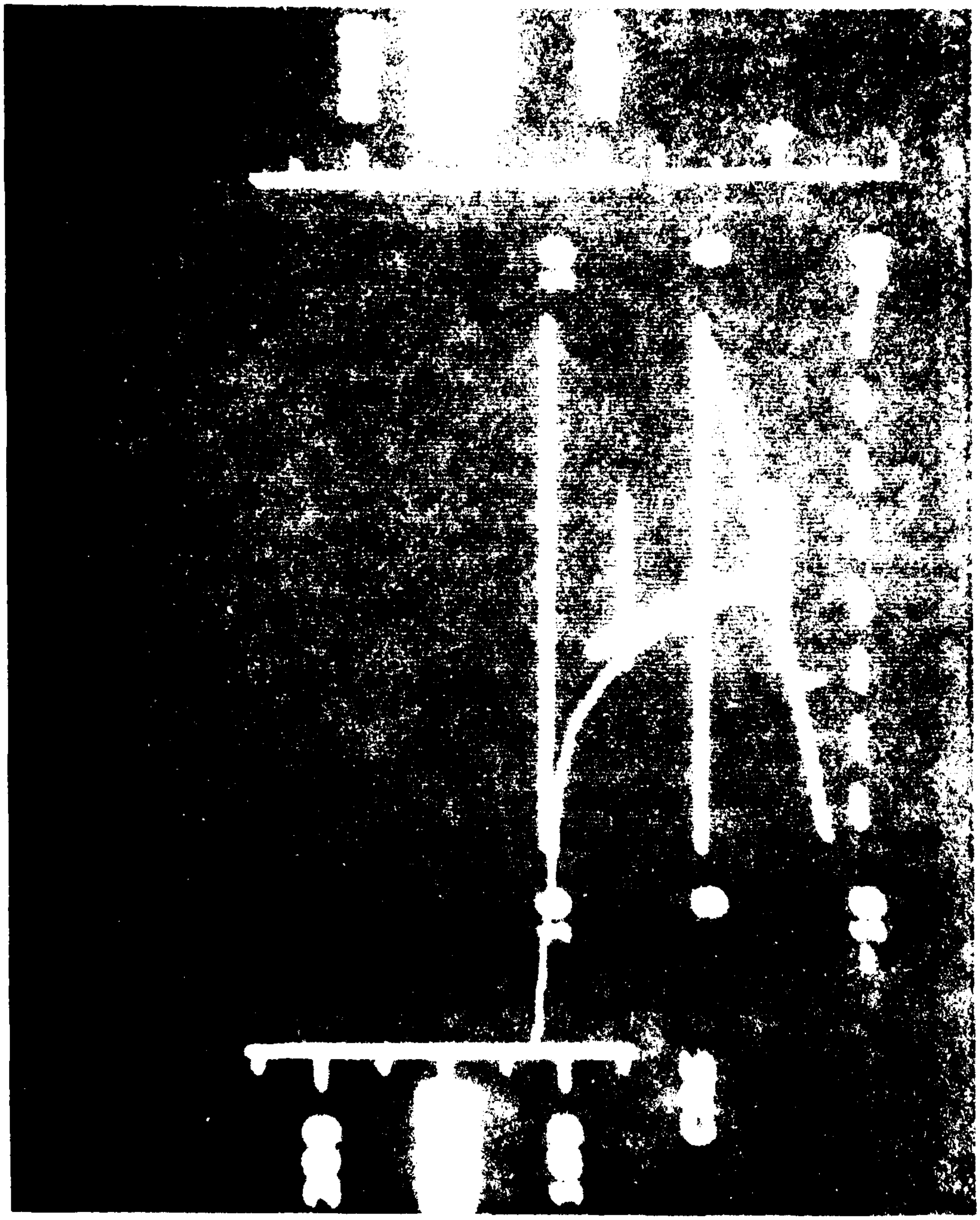
APPENDIX E

DISPLAY SAMPLES

NAME	SYMBOL	COLOR
Display Background		Black
Aircraft Symbol		Green
Pitch Scale		White
Airspeed Scale		White
Altitude Scale		White
Pitch Command Bars		Red
Path Predictor		Blue
Approach Profile		Red
Glideslope Scale		Red
Glideslope Deviation Indicator		White


10
0
-10
10
0
-10





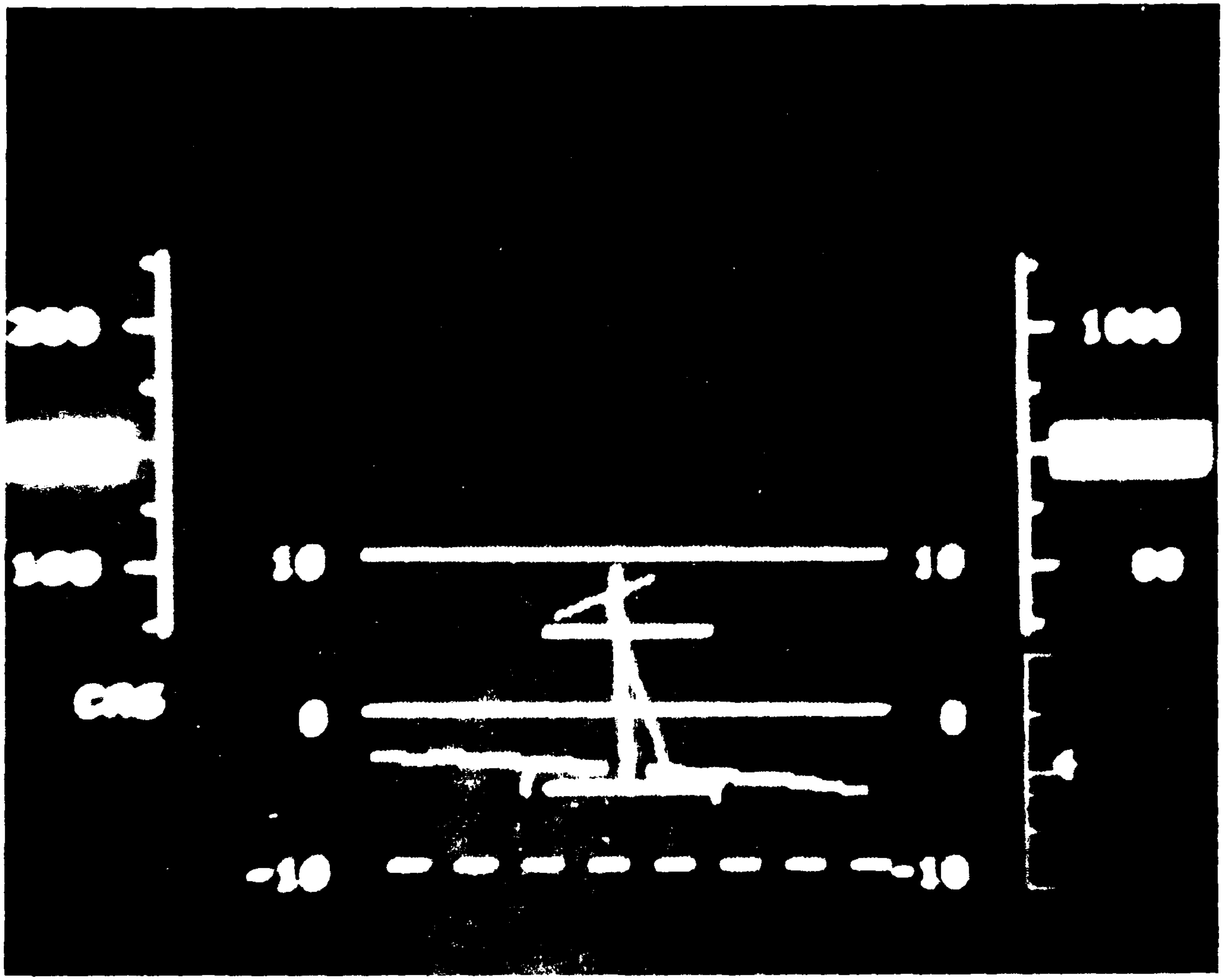


Figure F-4. Final App[illegible]
[illegible]
[illegible]

APPENDIX F

STATISTICAL PROCEDURES USED IN DATA ANALYSES

Since flying is inherently multidimensional in nature, several flight performance measures were recorded: crosstrack error, pitch steering error, glideslope error and airspeed error.

Amplitude distribution measures showing the variation of these parameters around nominal values were recorded for the flight performance. Then, the frequency at which specific deviations occur could be determined as a function of the amplitude of deviation. Measures of the amplitude distribution included: average error (AE), average absolute error (AAE), root-mean-square (RMS) error, and standard deviation (SD; Reference 1).

The AE is a numerical index of the central tendency of the amplitude distribution, while the SD reflects the variability of dispersion of the measures around this central tendency. RMS error is also an index of performance variability, but relative to the null point rather than the AE. AAE is the mean of the amplitude distribution replotted with all error amplitudes positive and is indicative of the variability when interpreted in conjunction with the other performance indices. These measures have been frequently used in human factors research and have been shown to be valid indicators for sensing differences due to experimental configurations (Reference 2).

When multiple performance measures are collected, it is appropriate to use a multivariate analysis of variance (MANOVA) routine since it considers all the dimensions of the task simultaneously and takes into account the correlations among the measures (Reference 3). During the conduct of the data analyses, the SPSS-MANOVA (Statistical Package for the Social Sciences) program available on the ASD CYBER 175 computer system (Reference 4) was utilized. An effect was defined significant if the probability that the

effect occurred due to random chance rather than due to experimental conditions was less than 5% ($p < 0.05$; determined by F ratio of variances and number of degrees of freedom; (Reference 5). This critical probability is frequently employed by statisticians in practice.

In those cases where the MANOVA revealed significant effects, the Krishnaiah Finite Intersection Test (FIT), a simultaneous comparison test for multivariate data, was utilized (Reference 6) to determine where the performance differences lie among the levels of the conditions evaluated and which of the performance measures are most sensitive to the conditions.

Data obtained from the rating scales and debriefing questionnaires was compiled to be presented in tabular form. Since the subjective data was measured according to a nominal or ordinal scale, the nonparametric Kolmogorov-Smirnov test was utilized to determine if the pilots significantly differed in their responses (Reference 7). The pilots' responses to the questionnaire items were determined to be significantly different if the probability for the corresponding critical test value of D and number of degrees of freedom was less than 0.05. Descriptive statistics were also computed on the biographical data collected to obtain an overall view of the pilot sample characteristics.

REFERENCES

1. Obermayer, R. W., and Muckler, F. A., Performance Measurement in Flight Simulation Studies, NASA-CR-82, July, 1964.

2. Cochran, W. G. and Cox, G. M., Experimental Designs, New York: Wiley, 1957.

3. Reising, J. M., Ward, S. L., and Rolek, E. P. "Some Thoughts on Improving Experiments," Human Factors, 1977, 19(3), 221-226.

4. Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K., and Bent, D. H., Statistical Package for the Social Sciences, McGraw-Hill Book Company, 1975.

5. Winer, B. J. Statistical Principles in Experimental Design, New York, McGraw-Hill Book Company, Inc., 1962.

6. Cox, C. M., Krishnaiah, P. R., Lee, J. C., Reising, J. M., and Schuurman, F. J. "A Study of Finite Intersection Tests for Multiple Comparisons of Means." In P. R. Krishnaiah (Ed.) Multivariate Analysis (Vol. V), Amsterdam: North-Holland Publishing Company, 1980.

7. Siegel, S. Nonparametric Statistics for the Behavioral Sciences, New York: McGraw-Hill Book Company, 1956.

☆U.S.Government Printing Office: 1981 — 559-005/4016

ATE

LMED

-8